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Objective assessment of stream segregation abilities of CI users as a function of electrode separation

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Introduction

Auditory streaming is a perceptual process by which the human auditory system organizes sounds from different sources into perceptually meaningful elements. Segregation of sound sources is important, among others, for understanding speech in noisy environments, which is especially challenging for cochlear implant (CI) users. Despite its high relevance in many daily situations, the number of studies investigating segregation abilities of CI listeners is limited and their findings are contradictory (e.g. Cooper and Roberts, 2009; Marozeau et al, 2013). Moreover, while most of the previous research assessed obligatory stream segregation, little attention has been given to voluntary stream segregation, a process where the listener actively tries to segregate the sounds. It is therefore unclear whether CI users are able to experience voluntary stream segregation as a function of electrode separation and whether this is perceived to occur instantaneously or to build-up over time.

Aim of the study

1. Determine whether electrode separation improves voluntary stream segregation in CI users.
2. Establish whether perceived stream segregation occurs instantaneously or needs time to build-up.

Method

A segregation-promoting paradigm, previously used in the normal-hearing literature (e.g. Nie et al. 2014), is used to objectively assess voluntary stream segregation abilities of CI users. Segregation abilities are assessed indirectly by making use of a temporal detection task: subjects are asked to detect a small delay applied to the last B-sound of a sequence of interleaved A- and B-sounds. While the B-sound stream is presented at a constant rate, the A-sound stream is highly irregular. Therefore, subjects need to judge the time between consecutive B-sounds to successfully perform the task. This becomes easier if the A- and B-sounds are segregated, leading to better performance (fig. 1). Moreover, if a two-streams percept needs some time to be built-up, performance will improve with sequence length.

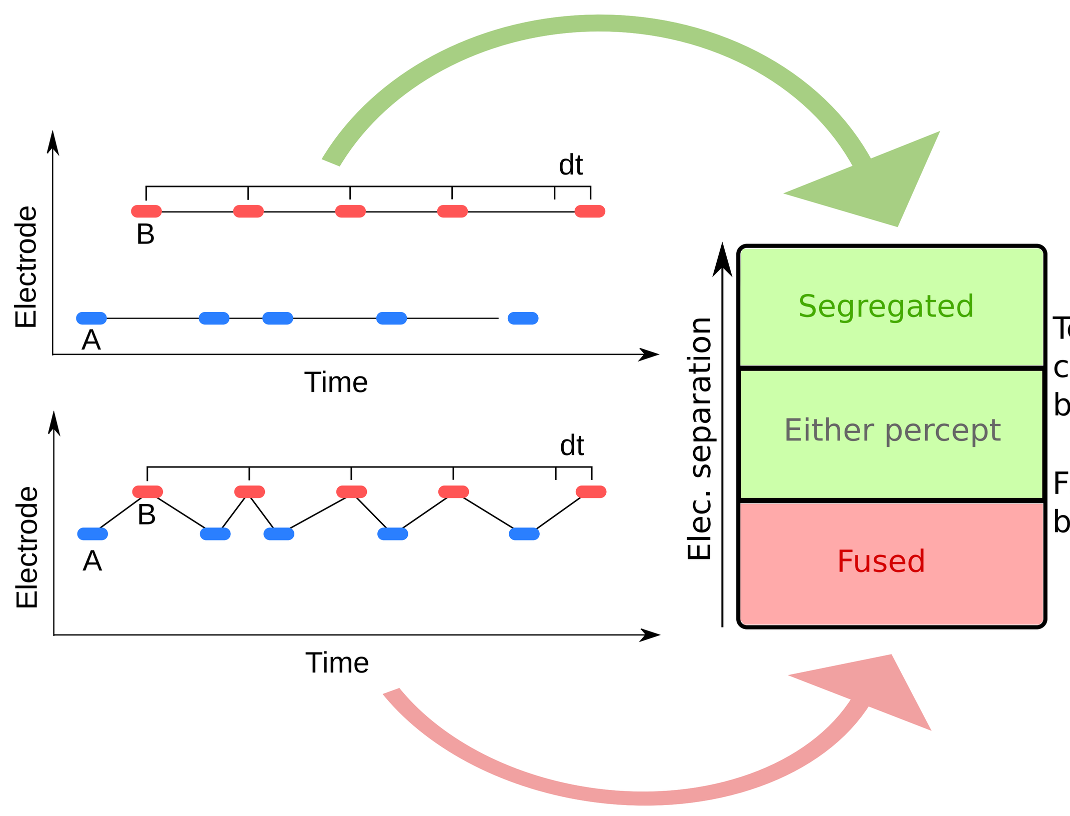

Fig. 1: Schematic representation of the paradigm.

Experimental design

- Go / no-go task (delayed / non-delayed sequence)
- Direct stimulation through Cochlear NIC2 interface
- B-stream: electrode 11
- A-stream:
  - Electrode 12 (small separation)
  - Electrode 19 (large separation)
  - Off (control condition)
- Stimulation rate: 900 pulses per second
- Long and short sequences (12 and 4 AB duplets)
- 60 presentations for each condition
- ISI B-stream: 340 ms (~3 Hz)
- ISI A-stream: 340 ms ± 220 ms
- dt adjusted for each subject (dt < jitter)

Participants

- 7 Cochlear CI users
- Ages from 19 to 78 years old (mean = 48, std = 27)

Delay (dt) adjustment procedure

The delay applied to the last B sound of the sequence (dt) was adjusted for each subject aiming to compensate for differences in performance across subjects.

- Sensitivity scores for delays of 5, 40, 80 and 120 ms were measured for the long sequence and for the large electrode separation condition.
- Each delay was presented 30 times
- A psychometric function was fitted to the sensitivity scores for the four delays
- The delay yielding a sensitivity score d' = 2 was chosen for each subject

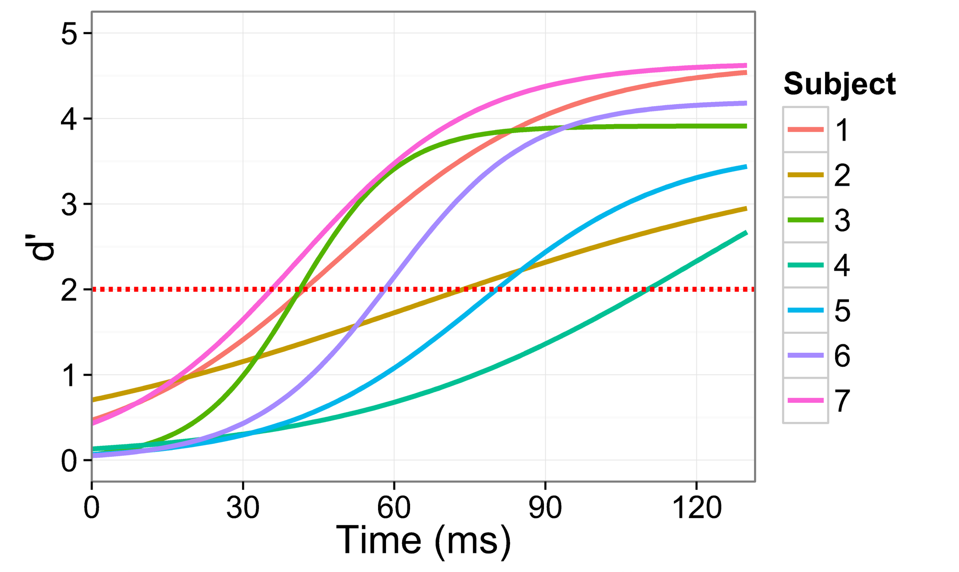

Fig. 2: Psychometric curve fitting for all subjects. The red, dashed line indicates the d' used for the adjustment of the delay applied to the last B tone of the sequence.

Results

Raw data

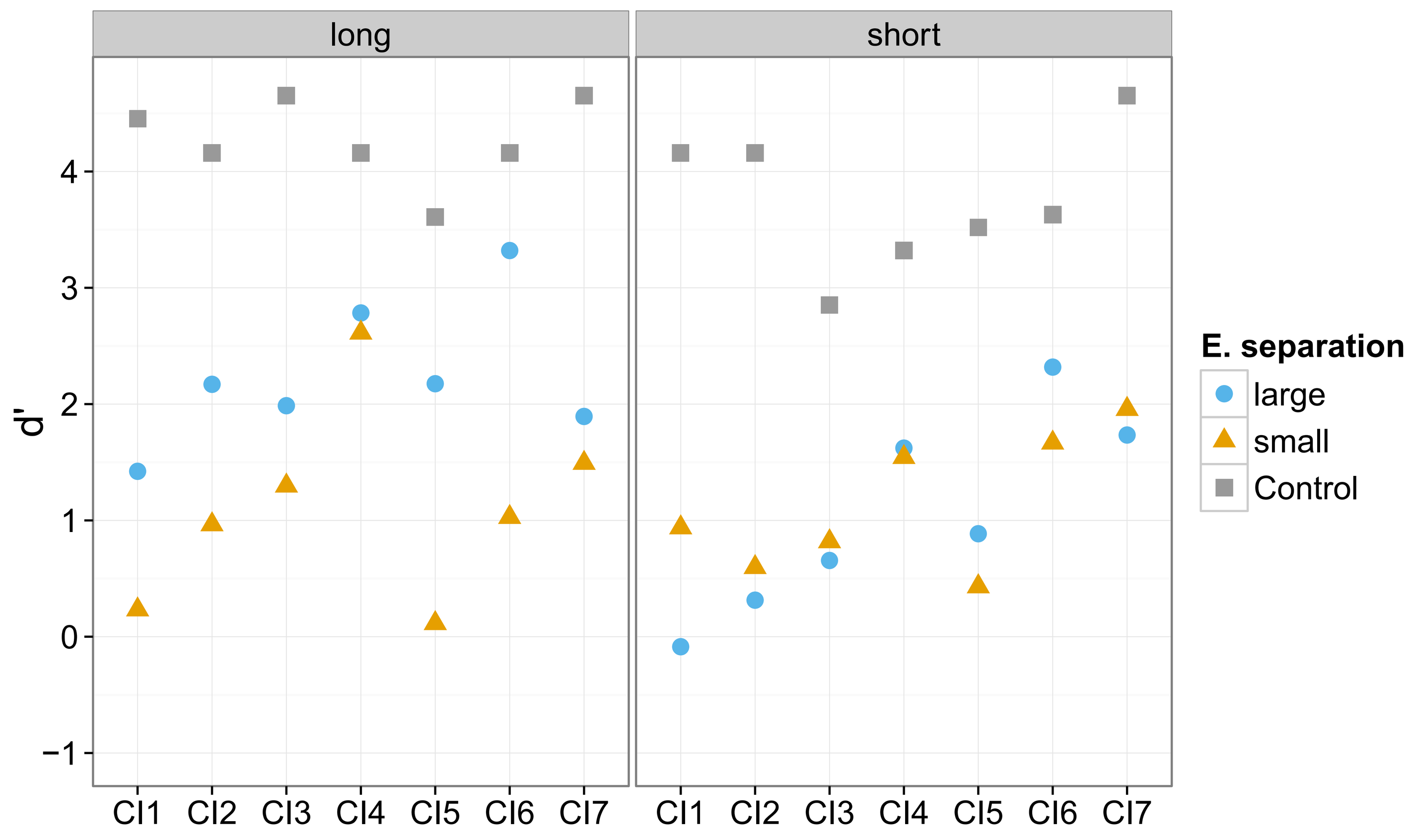

Fig. 3: Individual sensitivity to the delayed tone (d') for each condition. Results for the long and short sequences are presented on the left and right panels respectively. The gray square markers represent the control condition (only B-stream), the blue circles the condition with a large electrode separation and the yellow triangles the condition with a small electrode separation.

Normalized data

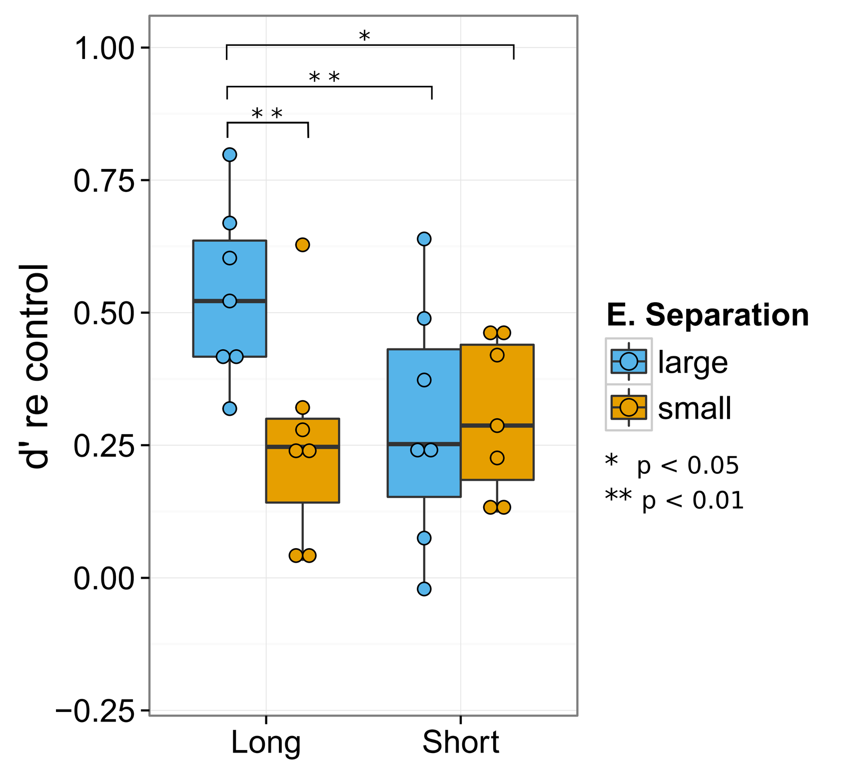

Fig. 4: Boxplot of the normalized data for all subjects grouped by condition. The d' scores for each subject and condition have been normalized with the respective control d' score. The blue and yellow boxes represent the large and small electrode separation, respectively.

Influence of A-stream jitter on performance

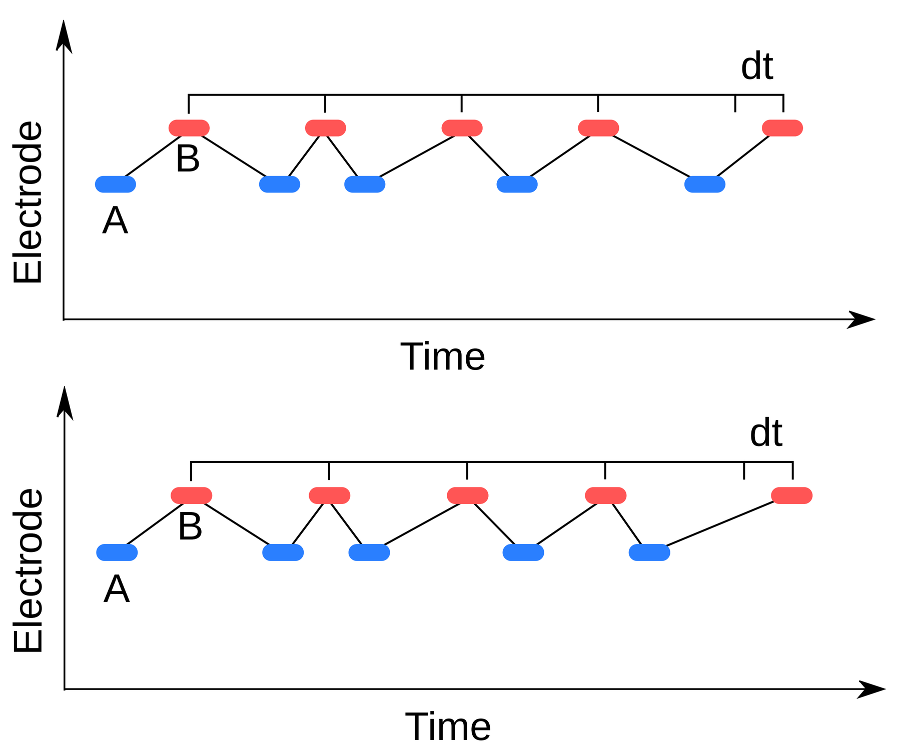

Fig. 5: Schematic representation of the effect of the jitter of the last A-sound on the response of the subject. If the A-stream influences the response of the subjects, they will better detect the delay for a negative jitter (lower panel) than for a positive jitter (upper panel), resulting on a correlation between subject's performance and A-stream jitter.

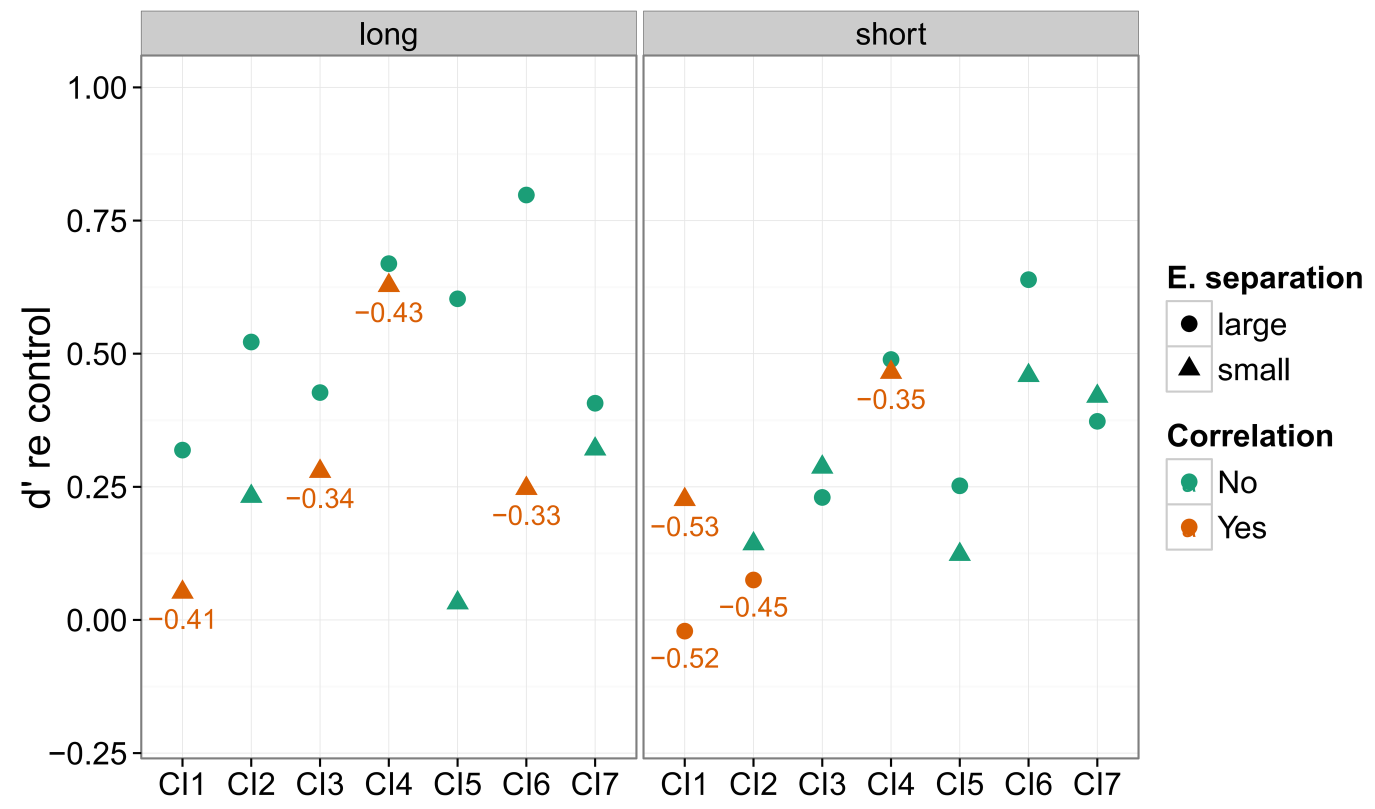

Fig. 6: Normalized sensitivity to the delayed tone (d') for each subject and its correlation with the jitter of the last A-sound of the sequence. Circular markers represent the condition with a large electrode separation and triangular markers the condition with a small electrode separation. Green markers indicate the lack of a significant correlation between the subject's performance and the jitter of the last A-sound while red markers indicate the presence of a significant correlation (correlation coefficient indicated below marker).

Main findings

- Large variability in sensitivity to dt across subjects (fig. 2)
- Significant improvement in performance with both electrode separation and sequence length (fig. 4), suggesting that:
  1. A large electrode separation facilitates voluntary stream segregation
  2. A two-stream percept needs some time to be built up (build-up effect)
- In the condition with a large electrode separation and a long sequence, performance is not influenced by the jitter applied to the A-stream, suggesting the successful segregation of the A and B streams (fig. 6)
- Subject's sensitivity to dt drops about 50% when introducing the distractor stream, even when target and distractor are segregated. This might indicate that longer sequences are needed for the build-up process to be completed (fig 3 & 4).

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